ANALYSIS AND DESIGN OF AIRFIELD PAVEMENTS USING LABORATORY TESTS AND MECHANISTIC-EMPIRICAL METHODOLOGY

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ABSTRACT

This paper describes the use mechanistic-empirical pavement analyses together with material properties determined from laboratory tests to design and evaluate performance of thick lift hot mix asphalt (HMA) pavements for large commercial aircraft loadings. Key material properties for the HMA are obtained from shear (AASHTO T-320, ASTM D-7312) and flexural fatigue (AASHTO T-321, ASTM D-7460) tests.

Use of shear test data to establish mix performance criteria for taxiways at the San Francisco International Airport (SFO) and mix design for the HMA used as the surface course for New Doha International Airport are briefly described.

Examples of full depth HMA structural section design for wide body heavy aircraft (e.g., Boeing 747-400, Boeing 777-800, Airbus 380-800, and Airbus 350-800) are included. The long life pavement designs include use of conventional and modified binders for the HMA, rich bottom layers in the pavement sections, and flexural strain criteria based on laboratory fatigue tests for the HMA mixes.

Associated with the design methodology is a discussion of construction considerations. Mix quality control including compaction requirements and limits on binder content and layer thickness variability as well as the use of tack coats for HMA multiple lift construction are discussed. In addition, preparation of the upper portion of the subgrade to insure proper HMA construction is discussed.

INTRODUCTION

This paper illustrates the use of Strategic Highway Research Program (SHRP) developed equipment to measure the permanent deformation and fatigue characteristics of HMA and their resulting test data for airfield mix and pavement design and analysis. The examples presented are limited to considerations of large commercial aircraft (wide body heavy aircraft) including the Airbus 380, Boeing 747, and Boeing 777.

The permanent deformation characteristics of HMA were obtained using a simple shear test (AASHTO T-320) (1). Resulting data have been used to: establish mix performance criteria for taxiways at the San Francisco International Airport (SFO) (2); and a mix design containing a polymer modified for the HMA for the surface course for the new Doha International Airport (NDIA), Qatar (3).

Examples of full depth HMA structural section design for wide body heavy aircraft (e.g., Boeing 747-400, Boeing 777-800, and Airbus 380-800 are included. The long life pavement designs include use of conventional and modified binders for the HMA, rich bottom layers (4) in the pavement sections, and flexural stiffness and fatigue characteristics (AAHTO T-321) (5) representing the HMA containing the different binders.

Associated with the design methodology is a brief discussion of construction considerations. Mix quality control including compaction requirements and limits on binder content and layer thickness variability as well as the use of tack coats for HMA multiple lift construction are discussed.

PERMANENT DEFORMATION EVALUATIONS

The constant height repeated simple shear RSST-CH) test was used to determine permanent response of the HMA. A shear stress of 10 lb/in^2 (69 kPa) was applied in the form of a haversine with a time of loading of 0.1 seconds and a time interval between load applications of 0.6 seconds. This combination of stress level and time of loading was selected because it has been used for a number of years at the University of California at Berkeley (UCB) Richmond Field Station (RFS) Pavement Materials Laboratory and has been validated for mix analysis and design purposes for highway loading conditions. Experience relating traffic loading and performance has shown these test conditions to be reasonable (6). The tests are normally conducted for 5,000 stress repetitions or to a permanent shear strain of 5 percent, whichever occurs first. An equation of the form:

$$\gamma_p = aN^b \tag{1}$$

is fit to the data, usually for the values of N $\geq$ 100 or 1000, depending on mix response. (N.B., this form of the equation was selected based on the log linear relationship between γ_p and N, usually after about 100 repetitions).

Data associated with the RSST-CH include shear stiffnesses at 50°C as determined from the relation:

$$G = \frac{\tau}{\gamma_{recov.}} = \frac{shear\ stress\,[69kPa(10\,psi)]}{recoverable\ shear\ strain\ at\ N = 100} \tag{2}$$

and, repetitions corresponding to a permanent shear strain of 5 percent (0.05). Air void content of the compacted specimens was determined using a wet with Parafilm procedure.

Because of permanent deformation occurring in the taxiways used for departures at SFO under the slow loading of B 747-400 aircraft, cores were obtained during the period August 1995 to January 1997. A number of different mixes were used to mitigate the permanent deformations occurring in this period. Table 1 indicates the mixes and approximate times at which the cores were obtained for shear testing. Shear test results for these cores are summarized in Figure 1.

Table 1 Sequence of Distress Development and Associated Rehabilitation Measures at SFIA

Location	Date	Problem	Remedial Treatment
Taxiway A	August 1995	Shoving and rutting from turning B747-400 aircraft	Increase aggregate size to 1-in. maximum and change asphalt grade to AR-8000 asphalt cement
Taxiway B1	October 1995	Severe rutting (dimpling) caused by stop-and-go movements of B747-400	Increase aggregate size to 1-in. maximum and change asphalt grade to AR-8000 asphalt cement
Taxiway B	June 1996	Severe rutting and shoving caused by stop-and-go movements of B747-400	Introduction of *High Stability* mix with AR-16000 asphalt cement
Taxiway B1	June/July 1996	Severe rutting and shoving caused by stop-and-go movements of B747-400	Place *High Stability* mix
Taxiway B	August/ September 1996	Localized slippage failures due to lack of bond between lifts caused by dust in surface of first lift	Replace mix in slippage areas with same *High Stability* mix; place and compact mix in one 4-in. thickness
Taxiway M	January 1997	Severe rutting and shoving caused by stop-and-go movements of B747-400	Place *High Stability* mix
Taxiway A	January 1997	Rutting and shoving in mix with AR-8000 and 1-in. maximum size aggregate	Place *High Stability* mix

Note that for a given mix, the number of repetitions to 5 percent permanent shear strain is a function of its air-void content, increasing as the air-void content decreases to a value of 2 to 3 percent. Below an air-void content of about 2 percent, the number of repetitions again decreased

(2). In Figure 1 the high stability mixes noted in Table 1 generally exhibit higher numbers of repetitions to 5 percent strain. While all the mixes that exhibited rutting in the taxiways met current FAA specifications, an enhancement to the current specifications was introduced to reduce the observed rutting. Mixes meeting these specifications were termed high stability mixes (2).

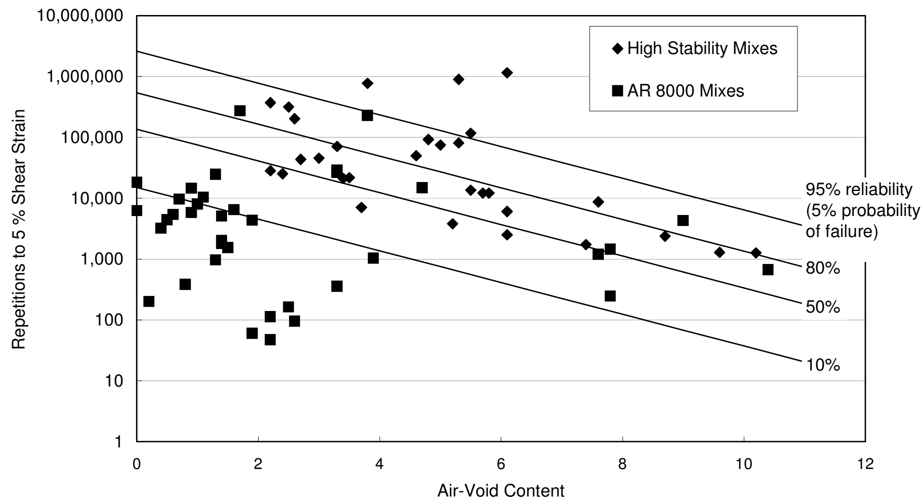


Figure 1 Shear stress repetitions to 5 percent shear strain versus air-void content at 50°C—all mixes. (2)

To establish criteria for mix design from these test results a logarithmic regression model was developed the results of which are shown in Figure 1. Equation (3) represents the probability of failure as function of air void content and aircraft repetitions. Failure is defined as the permanent deformation in the HMA causing rut depths considered detrimental to aircraft operations.

$$Probability\ of\ \ Failure = \frac{1}{1 + \exp(-11.8119 + 0.6002 \cdot AV + 0.9995 \cdot \ln N)} \quad (3)$$

Where: AV = percent air-void content, and
N = repetitions to 5 percent shear strain.

Figure 1 contains isolines of probability of failure corresponding to values of 5, 20, 50, and 90 percent. Thus, based on Figure 1, tentative criteria for mix design using the shear test (RSST-CH) can be established for different probabilities of rutting failure. Allowable repetitions to failure in the RSST-CH for probabilities of failure of 20 to 50 percent, at an air-void content of 3 percent are as follows (2):

Reliability percent	Probability of Failure, percent	N_p at γ_p = 5 percent
50	50	25,000
60	40	35,000
80	20	100,000

For new mix designs, results of the shear tests on mixes compacted at about 3 percent air voids over a range in binder contents are then plotted as shown schematically in Figure 2. Using a probability of failure (rutting of the type occurring on the SFO taxiways) of 20 percent (80 percent reliability), *N* at 5 percent shear strain of 100,000 is selected for the design binder content.

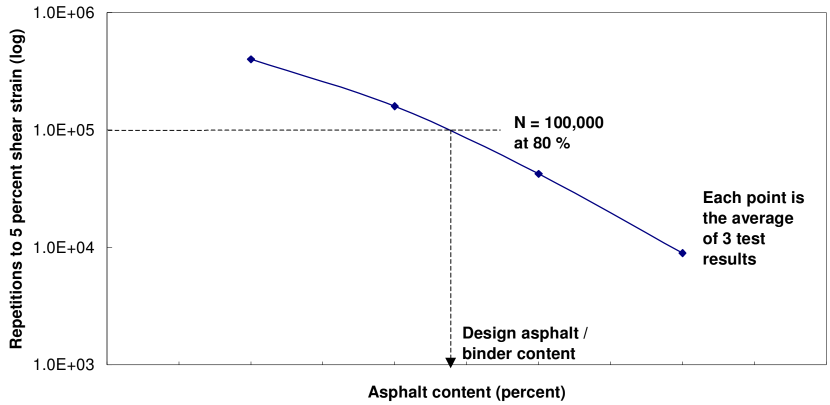
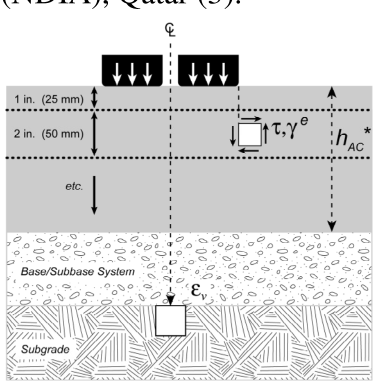


Figure 2. Schematic representation of binder content selection in the mix design process (2).

There has been discussion of the use of stiffness to differentiate mix performance. The results of this study as well as other investigation have indicated that stiffness alone is not sufficient for mix design and that repeated loading is necessary to arrive at a design binder content, particularly for heavy duty pavements and mixes containing modified binders (7).

As a part of the mix design process it is desirable to estimate rutting in the pavement structure from trafficking due to the mix. For this estimate, a methodology to be used herein has been described elsewhere (6). This procedure utilizes the RSST-CH data described earlier as well as stiffness characteristics and thicknesses of the pavement layers. In this approach, the pavement is assumed to behave as a multilayer elastic system for determination of key stresses and strains to permit rutting estimates to be made at the pavement surface. Figure 3 illustrates the idealization of a pavement structure which was used to estimate the accumulation of plastic strain which is related to rutting. The example used to illustrate the approach is the mix design containing a polymer modified binder for the HMA used in the surface course for the new Doha International Airport (NDIA), Qatar (3).



*h_{AC} can be subdivided into 3 or more layers for the layered elastic analysis

Figure 3 – Pavement idealization for accumulation of plastic strain (1)

Rutting in the asphalt concrete is assumed to be controlled by shear deformations. Accordingly, computed values for τ and γ^e at 2-inch (50 mm) depth beneath the edge of the tire were used for the estimates of plastic strain, as shown in Figure 3. In simple loading, permanent shear strain in the asphalt concrete is assumed to accumulate according to the following expression:

$$\gamma^i = a' \cdot \exp(b'\tau)\gamma^e n^c \qquad (4)$$

where:

- γ^i = permanent (inelastic) shear strain at a 2-inch (50 mm) depth
- τ = shear stress determined at this depth using elastic analysis
- γ^e = corresponding elastic shear strain (determined from τ and G)
- G = shear modulus
- n = number of axle load repetitions
- a', b', c = experimentally determined coefficients

Plastic (or inelastic) strain in the asphalt concrete layer due to shear deformation was computed using a time-hardening principle (6). To estimate the contribution to deformation from base and subgrade, a modification to the Asphalt Institute subgrade strain criterion was utilized (6). This approach permits prediction of plastic strain as a function of the following: traffic, environment, mix parameters, stiffness (dynamic modulus measured in the simple shear test) and permanent strain vs, repetitions from the RSST-CH test.

To address the anticipated performance of the materials as a function of the environment, pavement layer geometry and aircraft traffic, triplicate specimens were fabricated (gyratory compaction to air void content of 7%±1%) at two asphalt contents: the "design" or "optimum" asphalt content (4.7%), and "optimum + 0.5%" (5.2%). Excess asphalt tends to make a mix more susceptible to rutting (or permanent deformation), hence the testing at "optimum + 0.5%." Frequency sweep tests were conducted at 3 temperatures 39, 68, and 115 ºF (4, 20 and 46ºC) and 3 frequencies (0.1, 1 and 10 Hz). Repeated shear testing was conducted at 122ºF (50ºC) for 5000 load cycles.

Shown in Figure 4 is a comparison of the modulus and permanent shear strain for the "optimum" and "optimum plus" mixes. Figure 5 illustrates the relationship between temperature and modulus for the "optimum" and "optimum plus" mixes. The effect of asphalt content on mix properties may be observed from Figures 4 and Figure 5. From Figure 4b note that the permanent shear strains for the "optimum" and "optimum plus" mixes are approximately 1.9% and 2.6%, respectively. From Figures 5a and 5b note that the moduli at 77ºF (25 ºC) for the "optimum" and "optimum plus" mixes are approximately 1,000 k/in^2 and 750 k/in^2, respectively. On the "plus" side of the optimum asphalt content, modulus decreases and permanent shear strain increases. These data underscore the effect of asphalt content on mix susceptibility to permanent deformation and, hence, the importance of HMA plant process control.

Having determined the asphalt concrete modulus as a function of temperature and frequency, an analysis of the NDIA pavement section with the anticipated traffic is summarized elsewhere (3). The actual pavement layer geometry and that idealized for the analysis

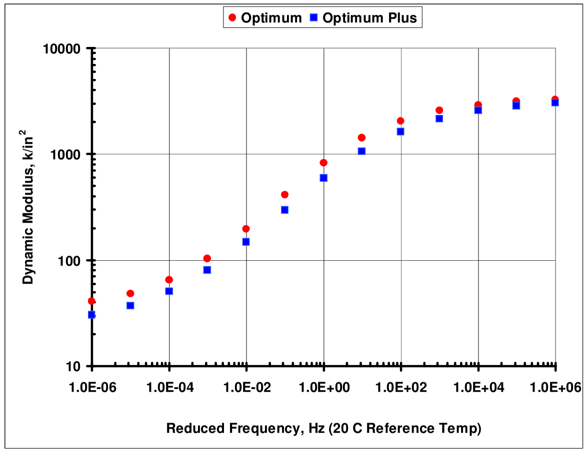


Figure 4a: Comparison of Asphalt Concrete Modulus for "Optimum" and "Optimum Plus" Mixes

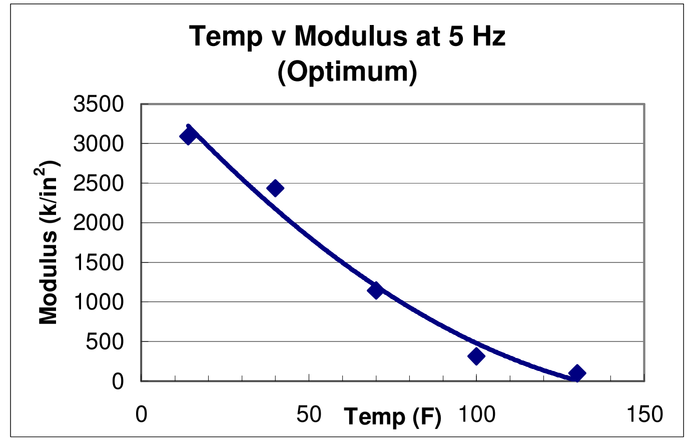


Figure 5a: 4.7% asphalt content

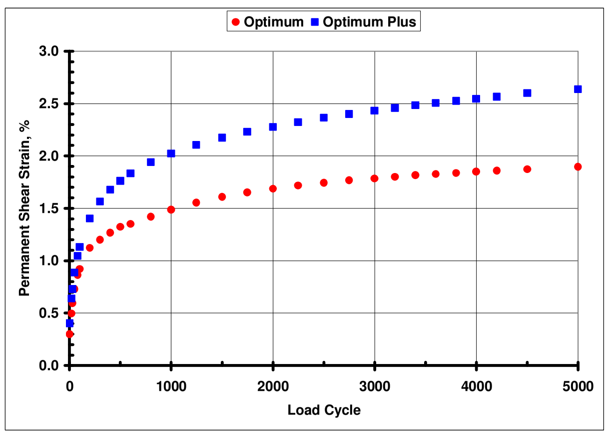


Figure 4b: Comparison of Permanent Shear Strain for "Optimum" and "Optimum Plus" Mixes content

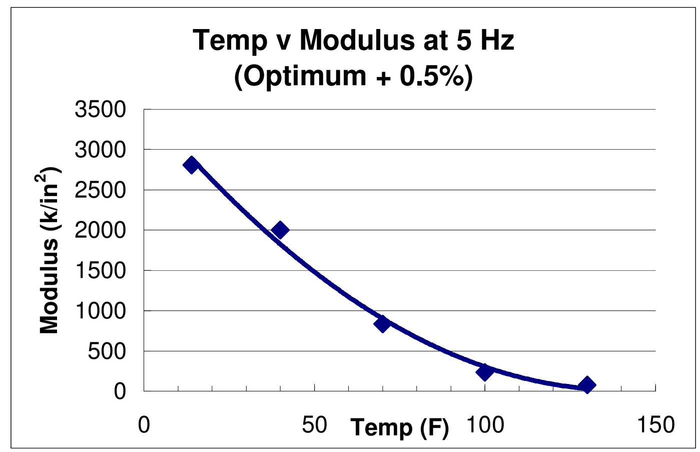


Figure 5b: 5.2% asphalt content

Figure 4 HMA Stiffness Modulus and Shear Test Data (3)

Figure 5 Asphalt Concrete Moduli vs. Temperature(3)

are shown in Table 2. The modulus of the asphalt concrete used in the analysis was based on the results of the frequency sweep testing. Poisson's ratios and moduli for the aggregate base and subgrade were assumed, i.e., taken from the published literature (3).

Table 2 ─ Pavement Layer Geometry and Material Properties

Pavement Layer	Actual	Idealized for Analysis	Material Properties
Asphalt Concrete	8 inches	20 inches Asphalt Concrete	E = f(temperature) 46,775 – 733,800 lb/in^2 ν = f(temperature) 0.40 – 0.45
Asphalt Treated Base	12 inches		
Aggregate Base	15 inches	15 inches Aggregate Base	E = 30,000 lb/in^2 ν = 0.30
Subgrade (CBR = 10)			E = 15,000 lb/in^2 ν = 0.30

The analysis focused on the weight and main gear configurations of the Airbus and Boeing aircrafts (8). Determination of critical stresses and strains in the pavement section were limited to two gear configurations: a four-tire configuration for the Airbus; and 6-tire configuration for the Boeing. Load per tire and tire pressure for the Airbus analysis were 56,000 lb and 220 lb/in^2, respectively while those for the Boeing analysis were 51,250 lb and 215 lb/in^2. Results of the CIRCLY (9) analyses indicated that the stresses and strains at the critical locations were comparable (3).

Table 3 – Summary of CIRCLY Analysis Output

	Airbus 330-220/300	Boeing 777-300
Shear stress at tire edge (lb/in^2)	66 - 68	63 - 65
Shear strain at tire edge	0.0004 – 0.0006	0.0004 – 0.0006
Vertical compressive stress at top of subgrade (lb/in^2)	9 - 13	11 - 12
Vertical compressive strain at top of subgrade	0.0007-0.0008	00.0006-.0007

Accumulations of plastic strains in the asphalt concrete were determined according to the procedure described above. In addition to the stresses and strains determined from the CIRCLY analyses, reasonable assumptions with respect to temperatures at the project site and aircraft operations were required to compute the plastic strain. The assumptions were as follows: aircraft operations uniformly distributed throughout the year; plastic strain accumulated during the warmest months, i.e., April-November; plastic strain accumulated 8 hours/day with one-half the aircraft operations at maximum weight; no aircraft wander was assumed; and, conservative value of shear modulus, G = 11,000 lb/in^2 at 122ºF (50ºC) was used.

Figure 6 shows predicted accumulation of plastic strain for the first 5 years. Several conclusions may be drawn from the data presented in Figure 6. For a well designed mix, the accumulation of plastic strain tends to level off very rapidly with time because of the inevitable ageing (i.e., hardening) of the asphalt cement with exposure to UV radiation. Mirroring the laboratory data shown in Figure 4b, the "optimum plus" mix shows considerably greater accumulation of plastic strain than does the "optimum" mix. From the laboratory test data presented in Figure 4b, the "optimum plus" mix sustains approximately 1½ times the plastic strain of the "optimum" mix. From the results presented in Figure 6, the "optimum plus" mix sustains approximately 2½ times the plastic strain of the "optimum" mix. The greater accumulation of predicted plastic strain is likely the result of the assumptions that were made (i.e., temperature distribution at the site, time over which plastic strain was accumulated, aircraft operations, and the use of model coefficients that were developed for highway loading conditions). This approach, though calibrated for highway loads, yields reasonable results for the aircraft considered and is consistent with the laboratory test results. It demonstrates the adverse effect of excess asphalt cement on permanent deformation.

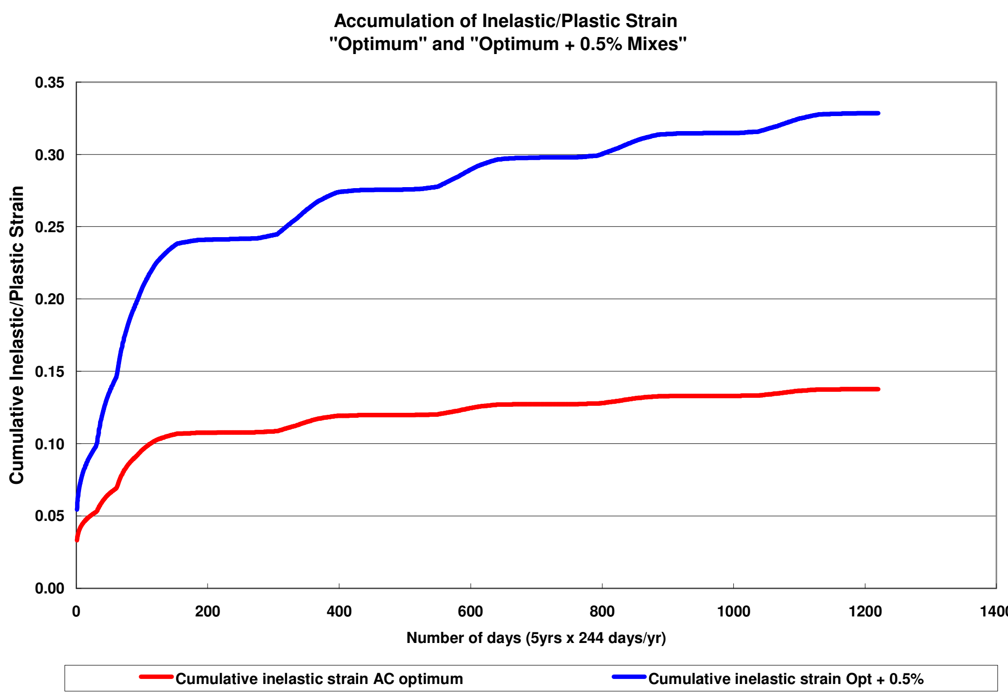


Figure 6 – Predicted Accumulation of Plastic Strain

Vertical compressive strains, ε_v, at the top of the subgrade generated from the CIRCLY analysis were used to estimate the influence of the Airbus and Boeing aircraft operations on permanent deformations in the unbound base and subgrade. An analysis based on the Shell criteria (10):

$$\varepsilon_v = 2.8 \cdot 10^{-2} \cdot N^{-0.25} \quad (5)$$

indicated that estimated load repetitions N, (to ¾ inch rutting) after 5 years of aircraft operations, would result in a relatively small contribution of the unbound materials to surface rutting (3).

PAVEMENT STRUCTURAL SECTION DESIGN EXAMPLES FOR WIDE-BODIED AIRCRAFT

Examples of full-depth HMA pavement sections for the wide-bodied aircraft (Boeing 747-400, Airbus 380-800, and Boeing 777-800) are briefly described in this section. Rather than the FAARFIELD Program (11), the mechanistic-empirical procedure incorporating the CIRCLY multilayer elastic program (9) and laboratory flexural fatigue and stiffness data for mixes containing PG (performance-graded) asphalt binders (both conventional and modified) were used. The pavement sections incorporate a combination of mixes including a surface layer containing HMA with a modified binder, an intermediate layer containing HMA with a conventional binder, and a rich-bottom layer using the same mix as the layer above but with increased binder content. The mixes in each layer were compacted to air void contents somewhat lower than required by conventional practice to improve their fatigue and/or permanent deformation characteristics (12). Table 4 lists the characteristics of the pavement structures.

Table 4. Pavement Structures for CIRCLY Analyses

Material Type#	Thickness (inches)	AC content (%)	AV content (%)	Poisson ratio	E (lb/in^2)
PBA-6a*	4	4.7	6	0.35	Variable
AR-8000	TBD	4.7	6	0.35	Variable
AR-8000, rich bottom	3	5.2	3	0.35	Variable
Aggregate base class 2	12	-	-	0.4	29000
SG		-	-	0.4	10875

After the mixes were tested, the binder types were reclassified (January 2006). The PBA-6a* binder is now designated as PG 64-28PM and the AR 8000 corresponds to a conventional PG 64-16 binder.

Stiffness moduli for the PBA-6a* and AR-8000 HMA were determined from equations from laboratory test data (12):

$$\text{PBA-6a*: } E(\ln \mathit{stif}) = 9.1116 - 0.1137\, \mathit{Temp} \quad (6)$$

$$\text{AR-8000: } E(\ln \mathit{stif}) = 14.6459 - 0.1708 AV - 0.8032 AC - 0.0549 \mathit{Temp} \quad (7)$$

where:

ln *stif* is the natural logarithm of the initial stiffness (MPa),
AV is the percent air void content,
AC is the percent asphalt content, and
Temp is the temperature in ºC.

Fatigue life, N_f, was determined from laboratory fatigue test data (AASHTO T-321) for the AR-8000 HMA with the following regression equation:

$$E(\ln nf) = -36.5184 - 0.6470AV - 6.5315 \ln stn \quad (8)$$

where:

ln *nf* is the natural logarithm of fatigue life,
AV is the percent air-void content,
ln *stn* is the natural logarithm of the tensile strain, ε_t , level.

Two climate regions were selected for the analyses/design of the pavement structures for each aircraft: 1) desert area of the Western U.S. as represented by temperature data for the International Airport, Yuma AZ; and, 2) coastal region of the U.S. adjacent to the Pacific Ocean by temperature data for the International Airport, San Francisco, CA. Temperature distributions through the depth of the pavement were obtained using EICM (Enhanced Integrated Climate Model) (13). Two months were selected: August as the hotter month (both sites); and January (Yuma) or February (San Francisco) as the colder month. Figure 7 illustrates temperature distributions in the HMA layer with depth for both sites.

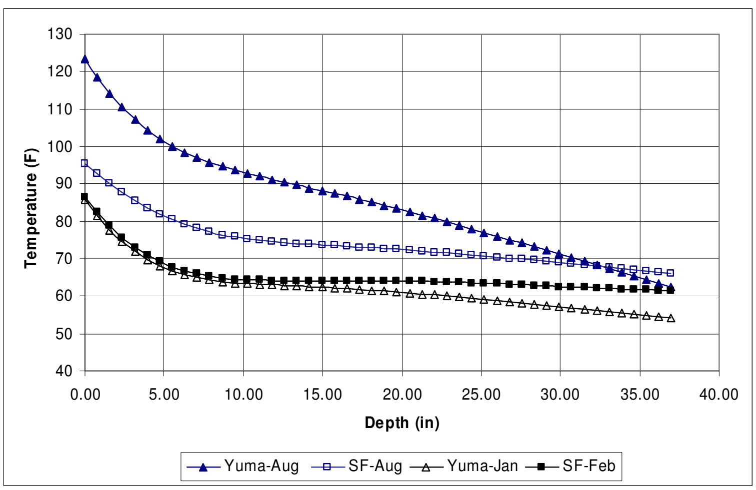


Figure 7. Average temperature vs. pavement depth for Yuma and San Francisco

Tables 5 and 6 contain the results of the CIRCLY analyses for Yuma and San Francisco. The thicknesses shown in the table are for the intermediate HMA layers; a total of 7 inches of HMA (4 inches for the surface and 3 inches for the rich bottom layers) must be added to the thicknesses. Thickness values corresponding to a strain at the bottom of the asphalt layer (AR-8000 rich bottom) of approximately 100 µs, 200 µs and 300 µs considering the hottest month stiffnesses were determined for each of the three aircraft considered. CIRCLY was used iteratively until a thickness producing the target strain was found. For Yuma, for example, a cumulative damage analysis for the three fully loaded aircraft, a total HMA thickness of 25 inches would be adequate for at least five million total operations with maximum take off weights for the three aircraft. For San Francisco the total thickness could be reduced to 20 inches. These thicknesses would also be satisfactory according to the subgrade strain criteria, equation (5).

Table 5. Yuma summary results

Linear Elastic analysis results for a hotter month of the year

	YUMA Intl Airport								
	Boeing 777	Boeing 777	Boeing 777	Boeing 747	Boeing 747	Boeing 747	Airbus 380	Airbus 380	Airbus 380
T_{AR8000}(in)	28	15	8	28	17	8	30	15	8
εt (μs)	110	210	330.5	114.3	196	345.3	116.9	202.1	335.9
εv (μs)	428	905	1337	405	764.7	1348	439	805	1205
N_f	1.42E+09	2.08E+07	1.07E+06	1.11E+09	3.27E+07	8.09E+05	9.56E+08	2.68E+07	9.69E+05
$E_{PBA\text{-}6a^*}$	14553	14553	14553	14553	14553	14553	14553	14553	14553
E_{AR8000}	891356	556932	450097	891356	594770	450700	756133	556932	450700
$E_{AR8000\ RB}$	1121868	692051	551509	1121868	742574	551509	932817	692051	551509

Linear Elastic analysis results for a colder month of the year

	YUMA Intl Airport								
	Boeing 777	Boeing 777	Boeing 777	Boeing 747	Boeing 747	Boeing 747	Airbus 380	Airbus 380	Airbus 380
T_{AR8000}(in)	28	15	8	28	17	8	30	15	8
εt (μs)	86.8	153	203	92.2	143	222	86.4	145.7	209.5
εv (μs)	350	708	1067	340	584	1054	346	656	933.5
N_f	6.68E+09	1.65E+08	2.60E+07	4.50E+09	2.56E+08	1.45E+07	6.89E+09	2.27E+08	2.12E+07
$E_{PBA\text{-}6a^*}$	121287	121287	121287	121287	121287	121287	121287	121287	121287
E_{AR8000}	1308838	1118460	1066559	1308838	1140835	1066559	1342793	1118460	1066559
$E_{AR8000\ RB}$	1531402	1291104	1212776	1531402	1321365	1212776	1563049	1291104	1212776

Table 6. San Francisco summary results

Linear Elastic analysis results for a hotter month of the year

	SF Intl Airport								
	Boeing 777	Boeing 777	Boeing 777	Boeing 747	Boeing 747	Boeing 747	Airbus 380	Airbus 380	Airbus 380
T_{AR8000}(in)	28	13	5	28	13	6	28	10	6
εt (μs)	110.4	197	301.2	115	204.7	318.3	112.8	224	310.2
εv (μs)	425.8	901	1473	403.3	861.6	1367	435	924	1225
N_f	1.39E+09	3.16E+07	1.98E+06	1.06E+09	2.46E+07	1.38E+06	1.21E+09	1.37E+07	1.63E+06
$E_{PBA\text{-}6a^*}$	45000	45000	45000	45000	45000	45000	45000	45000	45000
E_{AR8000}	908294	779268	712957	908294	779268	730493	908294	763940	730493
$E_{AR8000\ RB}$	1054073	892029	838493	1054073	892029	845148	1054073	870576	845148

Linear Elastic analysis results for a colder month of the year

	SF Intl Airport								
	Boeing 777	Boeing 777	Boeing 777	Boeing 747	Boeing 747	Boeing 747	Airbus 380	Airbus 380	Airbus 380
T_{AR8000}(in)	28	13	5	28	13	6	28	10	6
εt (μs)	98.3	173.2	269.4	103	177.9	261.1	102.4	180.8	253
εv (μs)	386	816	1321	368.8	769	1238	403.2	828.9	1084
N_f	2.96E+09	7.33E+07	4.09E+06	2.18E+09	6.16E+07	5.02E+06	2.27E+09	5.54E+07	6.17E+06
$E_{PBA\text{-}6a^*}$	112870	112870	112870	112870	112870	112870	112870	112870	112870
E_{AR8000}	1088924	1026545	1010024	1088924	1026545	1017784	1088924	1113998	1017784
$E_{AR8000\ RB}$	1239618	1152120	1146838	1239618	1152120	1147653	1239618	1287847	1147653

These analyses made use of the linear sum of cycle ratios cumulative damage hypothesis (Miner hypothesis for fatigue damage accumulation). Both tensile and vertical compressive strains at 25 and 20 inch thicknesses were interpolated from the data in tables 5 and 6. Strains at both the hotter and cooler months were utilized and traffic was apportioned based on the temperature distributions throughout the year at both locations.

Consideration was also given to the use of a stiffer base for Yuma using a PG 70-10 binder. Fatigue data for this mix are represented by the following regression equation:

$$E(\ln nf) = -19.88818 - 5.1427 \ln stn - 3.5919 \ln temp \text{ (in °C)} \qquad (9)$$

This mix was considerably stiffer; however, the fatigue response represented by equation (9) produced shorter lives at the strain levels as compared to equation (8) (with an AR-8000 binder [Comparable to a PG 64-16]). Accordingly, reduction in thickness of the intermediate layer was not possible. This emphasizes the importance of having laboratory data available for the specific mix or mixes to be used in major projects of this type. It should also be noted that equation (8) for the AR-8000 mix, based on a regression analysis of the fatigue data for 44 test specimens, indicated that the effect of air void content was the primary factor influencing fatigue response. In this instance the small difference in binder content (0.5 percent) between the rich bottom mix and the mix used in the majority of the of HMA base was not considered significant. However, this may not necessarily be the situation for all HMA mixes.

CONSTRUCTION CONSIDERATIONS

Construction control is extremely important for long lasting HMA airfield pavements. In a previous section which briefly described the evaluation of rutting for the HMA to be used for the surface course for the NDIA pavement, the results of the shear tests suggested that close control of the binder content was required. In general the most important control during construction for HMA production is the binder content. This is illustrated in Figure 12; based on an analysis for highway pavement loading conditions (14). The relationships presented indicates that adhering to the target binder value and with only a small standard deviation in this parameter

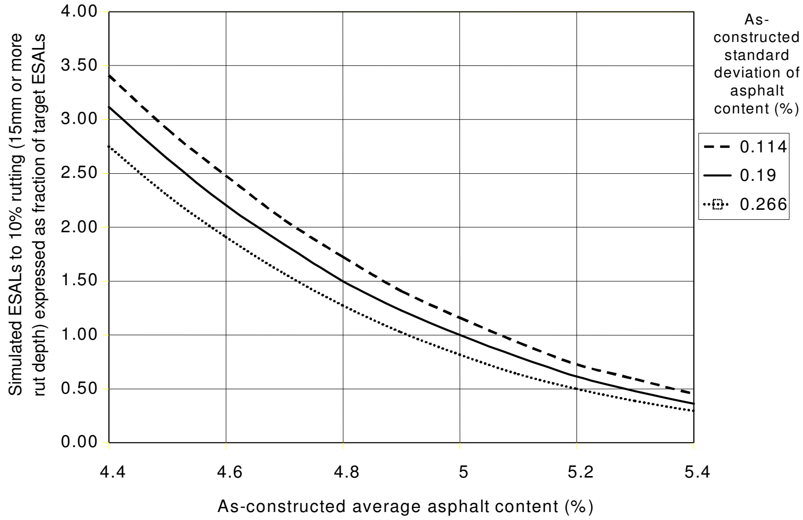


Figure 8 Influence of as-constructed asphalt content on rutting performance

(in this example, 5 percent for the binder content and a test variance of ± 0.3 percent - 0.19 percent with test variance excluded) will minimize the probability for significant rutting.

Stringent compaction control for this type of pavement is also necessary. For the upper HMA layers of the pavement section, in this example surface and intermediate layers, the HMA should be compacted to air void contents in the range 4 to 6 percent (based on ASTM D2041). For the rich bottom layer used in this example, the binder content is increased by 0.5 percent to insure that the mix can be compacted to an air void content of 0 to 3 percent (ASTM D2041). The fatigue life is increased markedly by this degree of compaction (14) and is necessary for long life performance. Similarly stringent requirements are mandatory for compaction of the untreated materials based on AASHTO T180); e.g. 100 + percent for untreated granular bases. Such construction requirements provide a stable working platform so necessary for proper compaction of the HMA layers.

Finally, it is imperative that a tack coat be used (e.g. PG 64-10 or PG 64-16) between lifts for the HMA layers to insure their responding to load as a single layer. Moreover this requirement will insure that breaking or sloughing forces at the surface from tires will not cause slippage in the upper portion of the pavement structure. (15).

SUMMARY

The purpose of this paper has been to illustrate the use of a combination of laboratory test data and mechanistic-empirical structural pavement analyses can be used to arrive at efficient designs for full depth HMA pavements to sustain a relatively large number of operations of wide bodied aircraft. Moreover it suggests the use of more than one binder type in the HMA pavement structure to take advantage of the influence of their physical properties and quantities on performance under heavily loaded aircraft in specific environments.

The use of the shear test has been demonstrated to be useful for both HMA mix design and for establishing performance criteria under repeated trafficking on taxiways. The laboratory test using a repeated shear stress of 10 lb./in.^{2} (69 kPa) was developed for highway pavements and large numbers of repetitions of traffic with tire pressures in the range 105 - 120 lb./in^2 (725 - 830 kPa) (7,8). While there has been limited application of the same stress level for mix evaluation for airfield pavements (e.g. References 2 and 3), some recent applications elsewhere for mix design for HMA taxiway and runway design have demonstrated that the SFO airport criteria (2) are suitable (16). Nevertheless it is desirable to continue to assess the application of RSST-CH to additional pavements.

It should also be emphasized that it is desirable to examine the response of the materials at more than one binder content to provide not only guidelines for construction control but also for more effective use of different quantities of binder in a specific mix in its location in the pavement structure. The use of the rich bottom concept is such an example. In this case, the rich bottom layer, because of its improved compaction requirements which are readily achievable, permits improved fatigue resistance to mitigate bottom up fatigue cracking and to prevent intrusion of water and water vapor into the layers above.

While one might argue that testing and analysis of this type are time consuming and expensive, the potential saving resulting in more effective use of materials and the ability to estimate long term performance more than offsets the cost for the significant financial investment and material requirements for projects of this type.

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